The Study of The Repair Material Effective for the Pavement Damage of the Smart Highway

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Abstract

Road construction has been actively carried out as a part of several 5-Year Economic Development Project in Korea to escape from railroad-dependent passenger and goods transportation. Since 1970s, Road has played the central role in transporting over 80% of goods and merchandises. As of the end of 2008, 28 highways stretching 3,400km are in operation currently.
The increase in traffic volume and global warming has caused rapid and early damage of road pavement in the 1990s, drawing increased attention to pavement maintenance/repair, and the "2008 Handbook of Road Operation Manual", published by Ministry of Land, Transportation & Maritime Affairs has attempted to switch its policy from new road construction and development to improvement in environmental, safety and capacity.
Especially, the improvement in quality of life and the development of IT and domestic automobile industry have changed the focus of domestic researchers and engineers to the construction of smart highway.
This study aims at developing the material and engineering method for rapid repair of road damage since smart highways are subject to pavement damage due to road impact load from over-speed driving to threaten the safety of highway users.
Thus, this study investigated and experimented with the repair materials for and status of road pavement in order to develop the material characteristics for the development of rapid repair technology appropriate for the damaged pavement of smart highway in Korea.

Keywords : Pavement damage, Local repair, Pavement repair/maintenance, Roughness, Performance, SMART Highway

1. Introduction

The Guide for Reduction of Potholes on Expressway of Korea Highway Corporation (2009) identifies potholes as the most common asphalt damage pattern. Field investigation and expert interviews of 120 locations subjected to highway asphalt pavement damage also indicated that potholes accounted for the largest percentage of asphalt pavement damage, followed by cracks and rutting, as shown in <Figure 1> below. Although rutting was the most common asphalt pavement damage pattern in the past, its occurrence has been reduced while potholes occur in increasing trend. <Table 1> illustrates the status of asphalt pavement status survey between Namyi JC (247.8km milepost) ~ Injook IC (306.8km milepost) of Joong-bu Expressway.

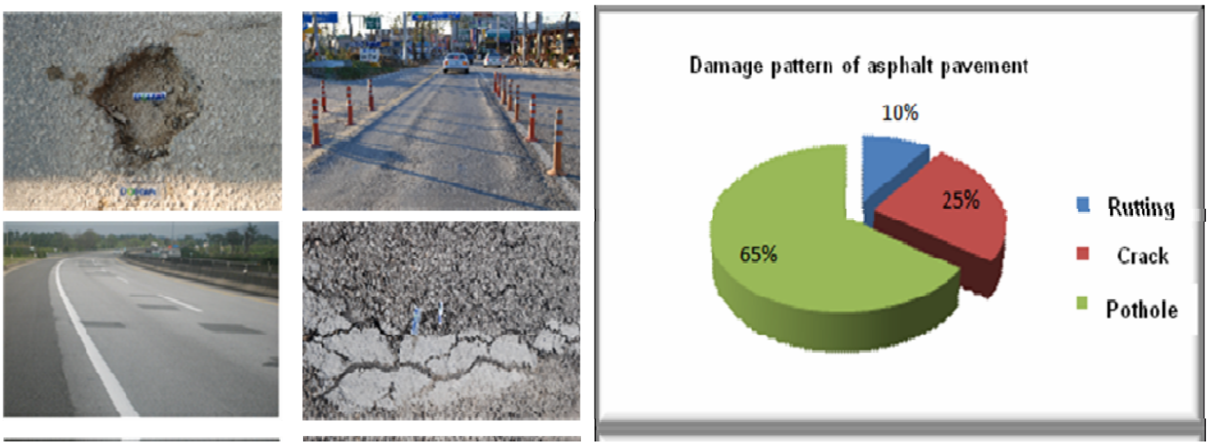


Figure 1. Pavement Damage Types

Table 1. Pavement Damage Status
(Highway and Transportation Technology Institute, Korea Highway Corporation)

Damage type		pavement type (extended analysis subject)		Damage ratio (B/A)
		CRCP (12.23km)	JCP (16.85km)	
transverse crack	number of locations	72	125	
	total length	120m	309m	
	average length (total length/number of locations)	1.67m/location	2.47m/location	1.48 location
longitudinal crack	number of locations	33 locations	29 locations	
	total length	35.67m	32.93m	
	average length (total length/number of locations)	1.08m/location	1.13m/location	1.05
pothole	number of locations	233 locations	121 locations	
	total area	7.47 m^2	163 m^2	
	average area (total area/number of locations)	0.032 m^2/location	1.35 m^2/location	42.19 location
alligator crack	number of locations	13 locations		
	total area	11.64		
	average area (total area/number of locations)	0.895 m^2/location		

It is important for smart highway to repair it and open for traffic as soon as possible and sooner than the repair speed required for existing highways when local pavement damage occurs due to various reasons. It is necessary to develop emergency repair material with economic competitiveness and the capacity for quicker manifestation of stiffness and strength equivalent to existing pavement materials and the construction technology to take the advantage. This rapid repair material should have unique properties, which can be applied to asphalt and concrete pavement differently. Additionally, it must repair local pavement damage caused by various reasons and must obtain the bond strength with existing pavement within the service requirement time after its repair and opening to traffic. This study analyzed the strength and weakness of existing pavement materials and derived the material properties for the development of the technology for the rapid repair of the local pavement damage based on this analysis.

2. Main Research Contents

2.1 Laboratory Test (Basic Material Properties)

Emergency repair materials currently produced in Korea were collected for the experiment and evaluation of rapid repair materials for local pavement damage appropriate for SMART Highway. The market for such repair materials sold in Korea is about \6 billion Korean Won, and three major companies (H company, H company, and S company) take about 96% of the market share for pre-mixed asphalt admixture producing industry. The repair materials currently used have risky in that they are often subjected to repeated damage after the repair of the damaged pavement because they are of normal temperature admixtures, which passed only minimal quality standard test and did not go through long-term performance evaluation. Thus, laboratory and field experiments were carried out to investigate their usage in Korea prior to the development of rapid repair/reinforcement materials with excellent durability, bond strength and verified service performance.
First of all, the production process and the strength and weakness as well as the actual samples of the rapid repair materials currently used in Korea were obtained with the cooperation for the production factories and their staffs. The status of rapid pavement repair products in Korea is shown in <Table 2> below.

Table 2. Status of rapid pavement repair products in Korea

usage	pavement type	product	strength and weakness	remark
Local repair (emergency repair of local pavement damage)	asphalt	H company R product	□ used over 80% for emergency road repair material □ paving possible as all-weather road repair material (water-proof, thin layer pavement, around manhole)	Specification prepared pursuant to KS F 2069
		H company B product	□ all-weather road pavement repair material □ 20% or over domestic market share	
		S company S product	□ black aggregate size 6mm □ all-weather emergency permanent repair material □ Relatively economical □ supplied to local government agencies	British product
		C company N product	□ water-soluble open for traffic within 20 minutes □ emergency patching even in heavy rain and snow □ currently used in many local offices of Korea Highway Corporation	factory produced
	concrete	H company S product	□ excellent bond-strength to existing surface □ possible for early opening for traffic owing to its shortened setting time	includes fiber material
		C company N product	□ water-soluble open for traffic within 20 minutes □ emergency patching even in heavy rain and snow □ currently used in many local offices of Korea Highway Corporation	factory produced
		S company B product	□ no-shrinkage regular type (Premixed Mortar) □ filling of bonding area between new and old concrete and repair/reinforcement of structures	

2.1.1 Laboratory Test (Asphalt)

Laboratory experiments were carried out to test the basic properties of the products currently produced in Korea and to analyze the performance evaluation based on the findings as shown in <table 3> and <Figure 2>. This laboratory experiments limited its scope to the products, which cooperated with this research and had large market share.

Table 3. Laboratory experiment method and purpose (asphalt)

mechanical test type	test method	test purpose
density	□ KS F 2446 : 2000 □ measurement of weight (immersion in water and dry saturation condition of the surface)	□ measurement of the density of the admixture □ analysis of compact condition of the pavement
Marshal's stability	□ KS F 2369 : 2008 □ loading at the speed of 50.8mm/min at 25℃	□ Marshal's mix design, measurement of stability at normal temperature
remaining stability after water immersion (%)	□ KS F 2369 : 2008	□ evaluation of resistance to debonding due to moisture
indirect tensile strength	□ KS F 2376 : 2001 □ loading at the speed of 50.0mm/min at 25℃	□ analysis of the pavement resistance to cracking □ prediction of pavement service performance
remaining indirect etnsile strength after water immersion		□ measurement of the sensitivity of the pavement to moisture

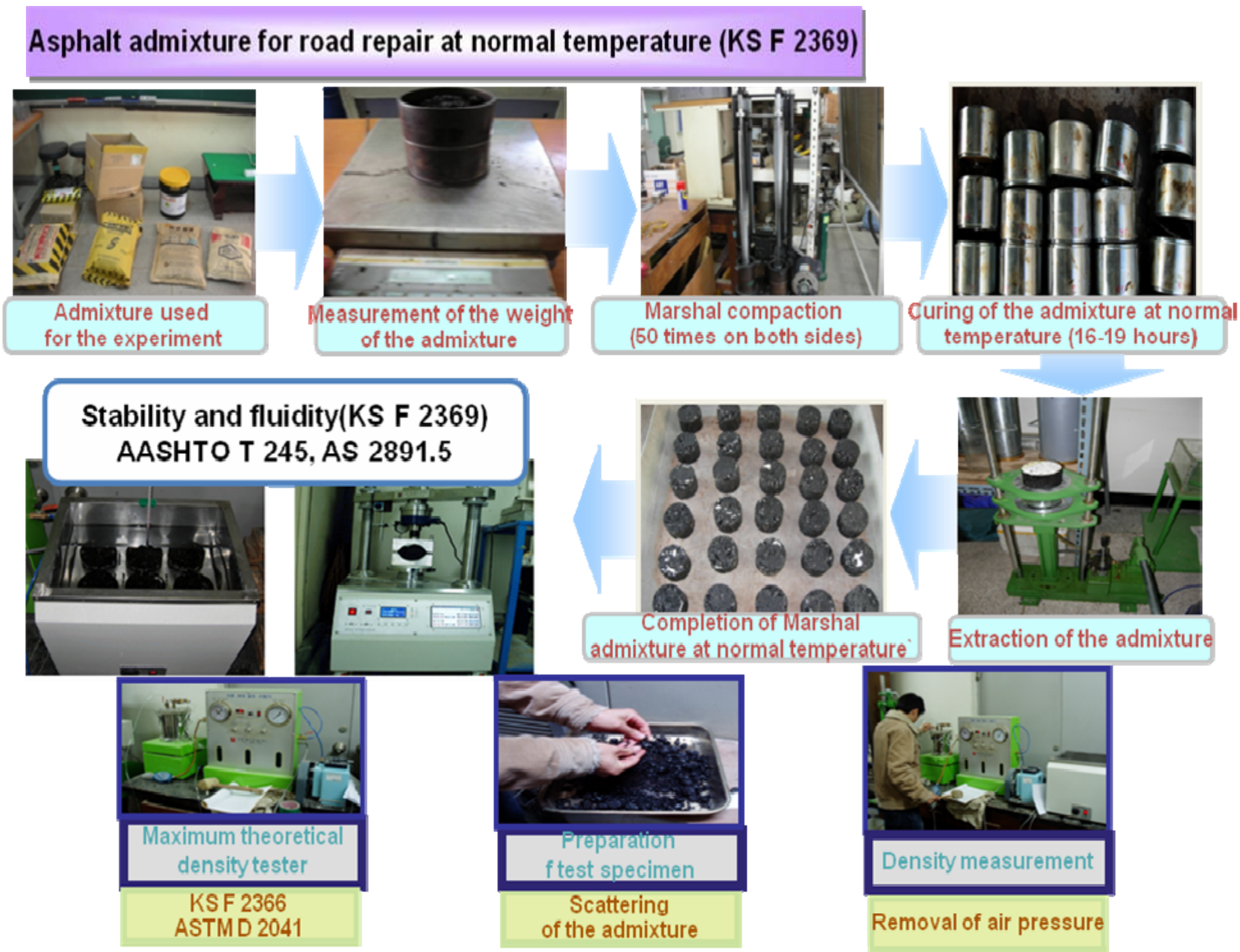


Figure 2. Laboratory experiment condition (asphalt)

① **Analysis of indirect tensile strength test**

Indirect tensile strength test is performed by applying once or repeated compressive loading along the vertical diameter to cylindrical test specimen as shown in <Figure 3> (KS F 2376).

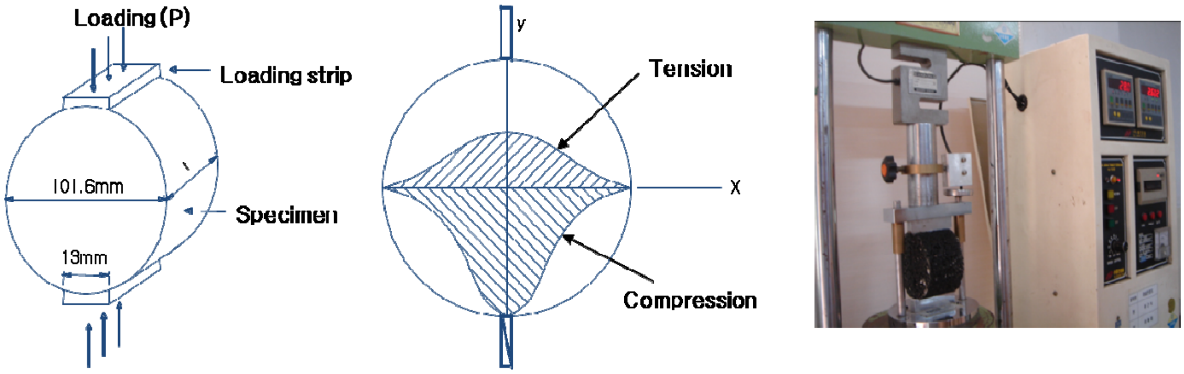


Figure 3. Principle of indirect tensile test and image of the tester

This loading type applies vertical loading along the vertical diameter section to cause relatively even tensile stress and finally cleave along the vertical diameter section to cause the specimen to rupture.
A loading platform with 12.7mm-width curvature is used to apply almost even stress on the specimen with 101.6mm diameter. A simplified process has been used since the development of the equations to compute the tensile stress during failure and tensile strain. This equation assumes the heated asphalt admixture is homogeneous, isotropic and elastic. Certainly, all these assumptions are not realistic, but the property evaluation based on these assumptions become the standard and is useful in evaluating the relative characteristics of the heated asphalt admixture. The equation to obtain the indirect tensile stress and strain at failure is given in the following.

$$\sigma_x = \frac{2p}{\pi dt}$$

$$\sigma_Y = \frac{6p}{\pi dt}$$

$$\epsilon_t = 0.52X_t$$

where, σ_x : horizontal tensile stress at the center of the test specimen
σ_Y : vertical compressive stress at the center of the test specimen
ϵ_t : tensile strain at failure
P : applied load
d : diameter of the test specimen
t : thickness of the test specimen
X_t : horizontal displacement of the test specimen (inch)

The above equation is applied when loading platforms with 12.7mm and 19.0mm curvatures are used on specimens of 101.6mm and 150mm diameters, respectively.
Indirect tensile strength test provides the characteristics of two admixtures useful for characterizing heated asphalt admixtures. The first is tensile strength, and this is frequently used to evaluate the sensitivity of the admixture to moisture. The original and remaining tensile strengths are measured to express the relationship in percentage for the evaluation of moisture sensitivity by taking the tensile strengths before and after the removal of the moisture. High tensile strength means better performance and vice versa. Additionally, tensile strength is used to evaluate the possibility of cracking of asphalt admixture. The second characteristics determined by indirect tensile strength test is the tensile strain at failure, and this is more useful in predicting the possibility of cracking. The admixture, which can withstand high strain prior to failure, will resist cracking better than the admixture, which cannot withstand high strain.
Indirect tensile strength is usually carried out at the deformation speed of 50.8mm/minute under the temperature condition of 25℃. If the strain or similar figure for 100mm specimen and 150mm

specimen is needed, the deformation speed of 76.2mm/minute is applied to the specimen with 150mm diameter. Actually, although the same machine speed is usually used for both specimens of 100mm and 150mm diameters, it is expected that the tensile strength measured for the specimen with 150mm diameter will be lower because of lower strain.

② Service performance evaluation (wheel tracking)

Wheel tracking is used for the evaluation method to select the admixture, which has excellent semi-rigid property during bitumen-heated admixture mix design and quality control. Since rutting occurs usually when vehicles move over asphalt concrete pavement during hot summer days, wheel tracking method was selected for the evaluation of rutting resistance by applying repeated wheel loading on the test specimen of bitumen-heated admixture to mimic the actual rutting caused by such wheel loading.
Wheel tracking test was developed by TRRL (Transport and Road Research Laboratory) of UK and is a test to evaluate the rigidity of asphalt admixture by modeling the influence of rutting or kneeding caused by heavy vehicle movements on actual road during hot weather in laboratory setting. <Figure 4> shows the principle of wheel tracking test, and it involves repeated back-and-forth movement of wheels on rectangular test specimen of 30㎝×30㎝×5㎝ dimension. Although the test vehicle moves back and forth in a straight line after the test temperature of 60±0.5℃ is reached on the surface of the test specimen, this study carried out the experiment at normal temperature of 25℃ in consideration of the characteristics of rapid repair material.

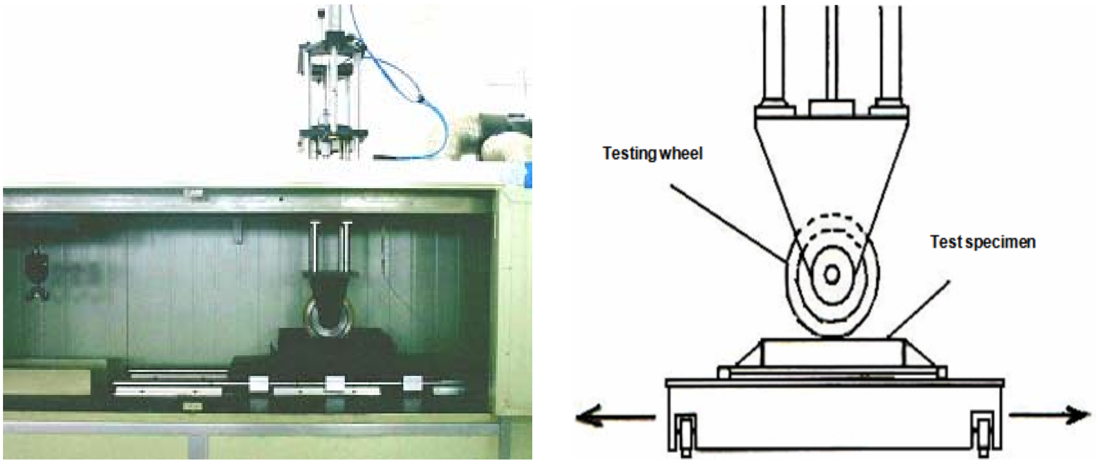


Figure 4. Principle of wheel tracking test

The result of wheel tracking test is represented by the rate of deformation and dynamic stability, and the former was measured the rate of deformation during the test time between 45 minutes and 60 minutes for 15 minutes during which the rate of deformation becomes almost constant. The latter indicates the number of times of which the wheels pass to deform the test specimen for 1mm. Generally, the admixture with high dynamic stability is deemed to be good for rut-resistance.
<Figures 5~7> shows the result of the wheel tracking test by the manufacturers. The dynamic stability result of the test could not be obtained for all B, S, and R test specimens. Additionally, although relative comparison with dense grade specimen was expected, the comparative analysis was not possible because all sample specimens failed during early stage. It is thus indicated that rapid repair materials function as a temporary means of simple emergency local repair rather than as a long-term or even short-term performance material.

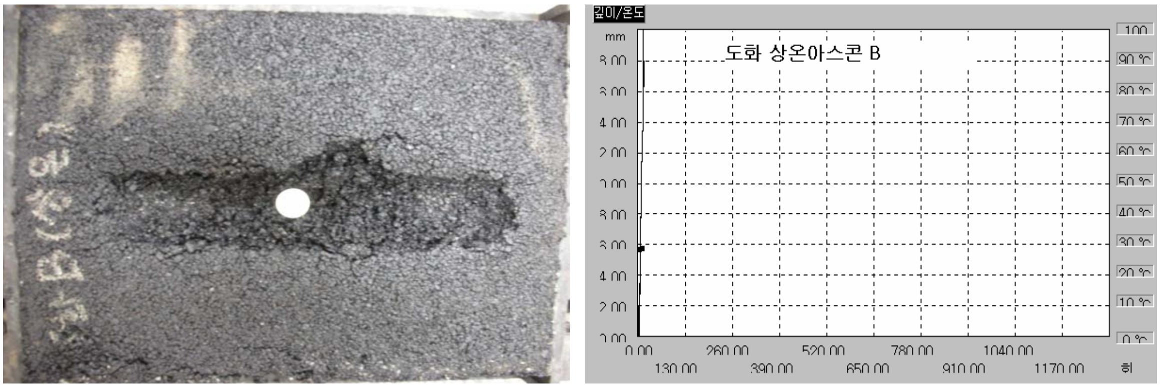


Figure 5. Result of wheel tracking test for B product of H company

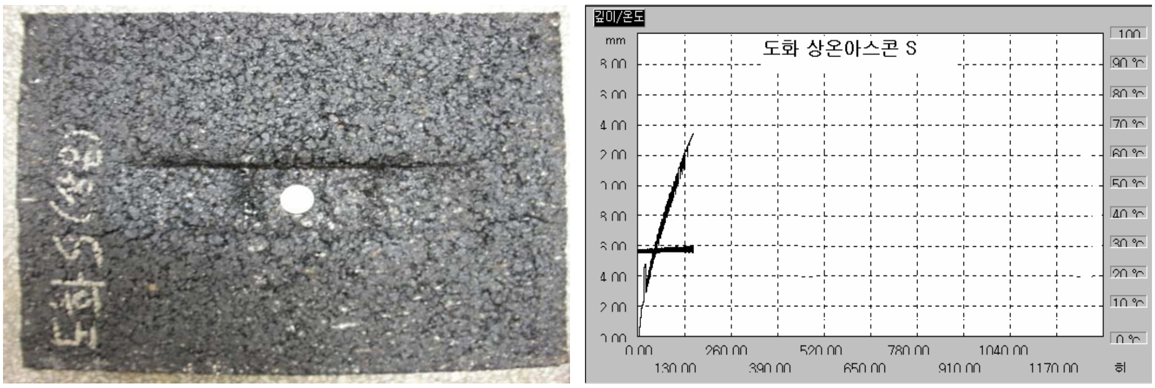


Figure 6. Result of wheel tracking test for S product of S company

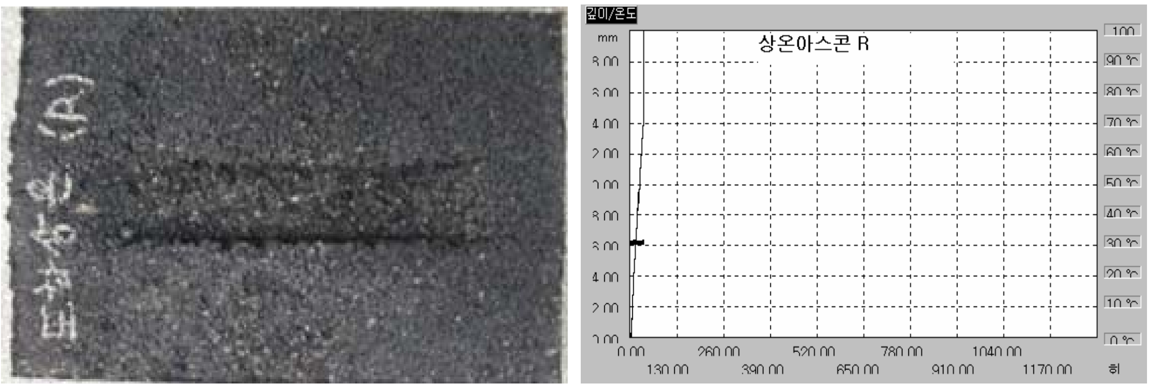


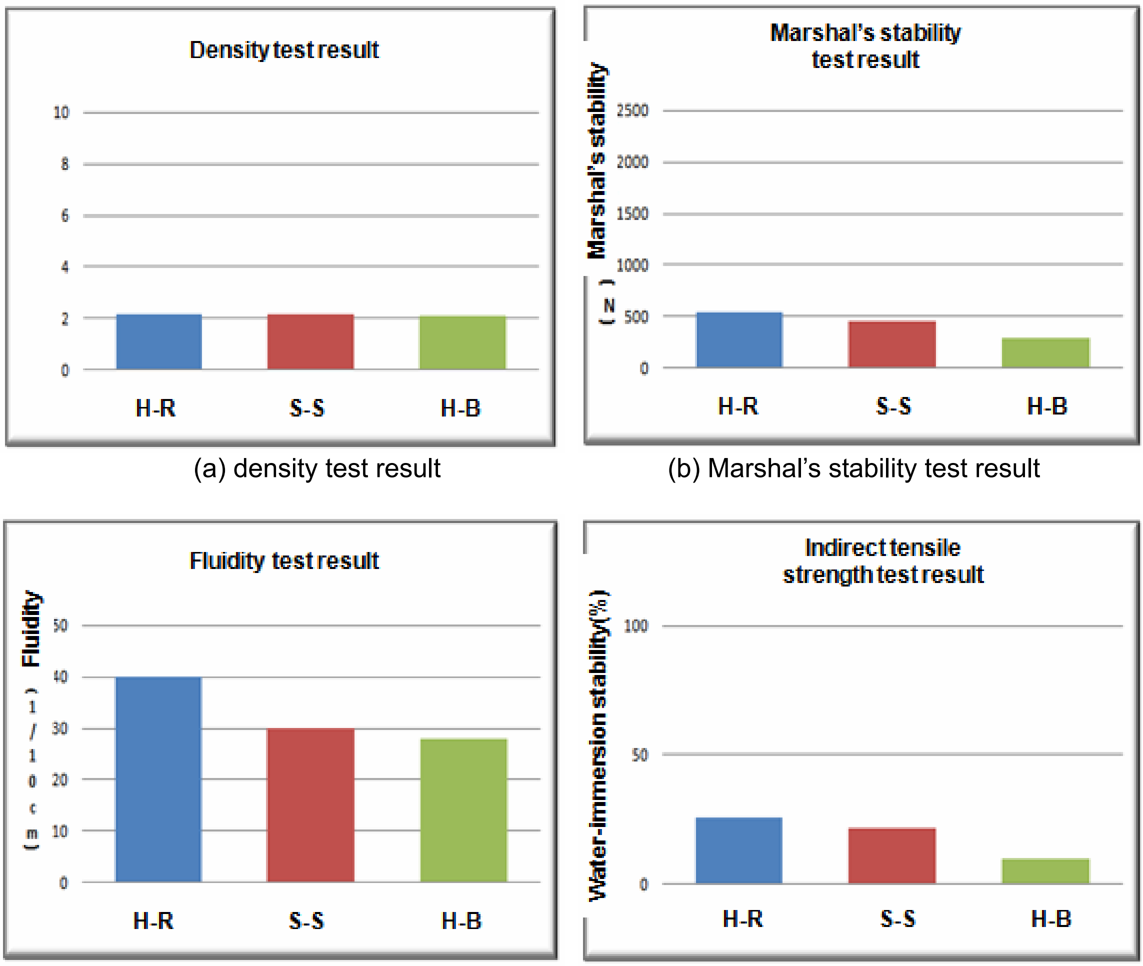
Figure 7. Result of wheel tracking test for R product of H company

③ Summary and analysis of the test results

<Table 4> and <Figure 8> show the results of asphalt admixture tests. While they exhibit a similar result with typical dense-grade asphalt material, the Marshal's stability and fluidity test results of all specimens did not pass the quality standard of 2,500N. The indirect tensile strength test result also exhibited high risk of cracking due to shear fracture, and it was determined that the comparative experiment was difficult to perform.

Table 4. Summary of laboratory test results (asphalt)

	quality standard	H company R product	S company S product	H company B product
density(g/cm^3)	-	2.205	2.170	2.130
Marshal's stability(N)	2,500	548	451	296
fluidity (1/10cm)	20~40	40	30	28
water-immersion stability(%)	75 이상	26	22	10
indirect tensile strength (kg/cm^2)	80	19.0	4.70	12.7
water-immersion remaining indirect tensile strength (%)	-	0.31 (N.G)	N.G	N.G
wheel tracking (㎜)	-	N.G	N.G	N.G



(a) density test result (b) Marshal's stability test result

(c) fluidity test result (d) indirect tensile strength test result

Figure 8. Laboratory test results

The research staffs carried out the laboratory experiments and found that there was some relative difficulty in observing structural stability of the asphalt admixtures.

2.1.2 Laboratory Test (Concrete)

Emergency repair materials for polymer concrete, which are currently produced in Korea, were collected for the selection of rapid repair material for local pavement damaged part appropriate for SMART highway, and basic properties of these materials were tested and evaluated as shown in <Table 5> and <Figure 9>.

Table 5. Laboratory test method and purpose (concrete)

mechanical test type	test method	test purpose
setting time Initial setting: 45 or above Final setting:10 or below	□ KS L 5210 : 2006 □ Initial setting: 45 or above, Final setting:10 or below	□ performed to investigate the setting time of rapid repair material for road pavement objectively
compressive strength MPa(N/㎟)	□ KS L 5210 : 2006 □ strength at 3hr, 1day, 3days, 7days	□ performed to examine basic properties of rapid repair material for road pavement
flexural strength (N/㎟)	□ KS F 4042:2007 □ 6.0 or above	□ performed to examine basic properties of rapid repair material for road pavement

Figure 9. Laboratory experiment images (concrete)

① Flexural strength and compressive strength

Flexural strength test involves measuring the maximum loading on the center of the specimen at the loading speed of 50±10N per second within the length of 100mm. It is computed by taking the average of three strengths obtained from the test. Compressive strength is performed on six specimens cut from the three specimens of one set for flexural test after the flexural test. Both sides of the specimens are subjected to the compression after molding, and compression steel plate of 40㎜×40㎜×40㎜ dimension is used for loading at the speed of 800±50N per second. This experiment was carried out pursuant to KS F 4042:2007 for polymer cement mortar for concrete structure repair, and the test results are shown in <Table 6> and <Table 7>.

Age (d)	Specimen No.	Max. Flexural Load (KN)	Flexural Strength (MPa)	Ave. Max. Flexural Load(F) (KN)	Ave. Flexural Strength (MPa)	Max. Compressive Load (KN)	Compressive Strength (MPa)	Ave. Max. Compressive Load(F) (KN)	Ave. Compressive Strength (MPa)
2h 30min	1	**Could not measure the strength (not hardened)**				**Could not measure the strength (not hardened)**			
	2								
	3								
	4								
	5								
	6								
1-d	1	**Could not measure the strength (not hardened)**				**Could not measure the strength (not hardened)**			
	2								
	3								
	4								
	5								
	6								
3-d	1	1.26	2.95	1.29	3.03	12.36	7.7	11.88	7.43
	2					11.38	7.1		
	3	1.28	3.00			12.26	7.7		
	4					12.14	7.6		
	5	1.34	3.14			11.26	7.0		
	6					11.90	7.4		
6-d	1	1.78	4.17	2.01	4.72	20.16	12.6	20.58	12.86
	2					20.54	12.8		
	3	2.28	5.34			21.58	13.5		
	4					20.66	12.9		
	5	1.98	4.64			20.34	12.7		
	6					20.21	12.6		

Table 6. Flexural and compressive strength of N product of K company

Age (d)	Specimen No.	Max. Flexural Load (KN)	Flexural Strength (MPa)	Ave. Max. Flexural Load(F) (KN)	Ave. Flexural Strength (MPa)	Max. Compressive Load (KN)	Compressive Strength (MPa)	Ave. Max. Compressive Load(F) (KN)	Ave. Compressive Strength (MPa)
2h 30min	1	1.78	4.17	1.80	4.22	18.52	11.6	18.80	11.75
	2					17.82	11.1		
	3	1.82	4.27			19.18	12.0		
	4					18.78	11.7		
	5					19.68	12.3		
	6					18.82	11.8		
1-d	1	2.06	4.83	1.92	4.50	28.10	17.6	28.40	17.75
	2					27.62	17.3		
	3	1.92	4.50			29.00	18.1		
	4					28.12	17.6		
	5	1.78	4.17			28.38	17.7		
	6					29.16	18.2		
3-d	1	2.08	4.88	1.94	4.55	32.90	20.6	29.24	18.27
	2					32.74	20.5		
	3	1.86	4.36			25.60	16.0		
	4					32.70	20.4		
	5	1.88	4.41			19.66	12.3		
	6					31.82	19.9		
6-d	1	2.12	4.97	2.31	5.42	38.50	24.1	36.63	22.89
	2					32.32	20.2		
	3	2.58	6.05			37.52	23.5		
	4					37.36	23.4		
	5	2.24	5.25			36.97	23.1		
	6					37.12	23.2		

Table 7. Flexural and compressive strength of S product of H company

The characteristics of rapid repair material require reaching the necessary early strength quickly. However, the result of testing the rapid repair material for concrete indicated that the final setting time was 5 minutes or below and did not pass the quality standard.

The result of flexural and compressive strength tests for mortar specimens revealed relative difficulty in long-term performance because they underwent early hydration very rapidly. Additionally, it was difficult to evaluate structural safety due to the slump loss, which reduced the consistency of the mix, by hydration and subsequent evaporation of the concrete mix.

Especially, it was found that products lacking workability urgently need to supplement the material characteristics by such means as adding additives like delay agents because of the rapid setting time of 5 minutes or less.

2.2 Field Test Construction

This study mimicked local damage of the pavement subjected to wheel loading in order to evaluate the long-term performance of domestic rapid repair materials appropriate for SMART Highway as shown in <Table 8> and monitored a total of eight types of such materials for various pavements including ordinary heated asphalt by compaction or non-compaction. <Figure 11> below illustrates images of field test construction. Monitoring is currently in progress, and the specimens did not show any problems in short-term performance except for the detachment of aggregate from particular products.

Table 8. Field test construction evaluation and purpose

Performance evaluation of field construction	Mechanical material property test
① roughness test (focusing on rutting, measurement of levelness) ② visual inspection (focusing on pothole and aggregate detachment) ③ field measurement of bond strength (measurement of bond strength between layers)	① shear strength test (direct evaluation of the bond strength of old and new materials)

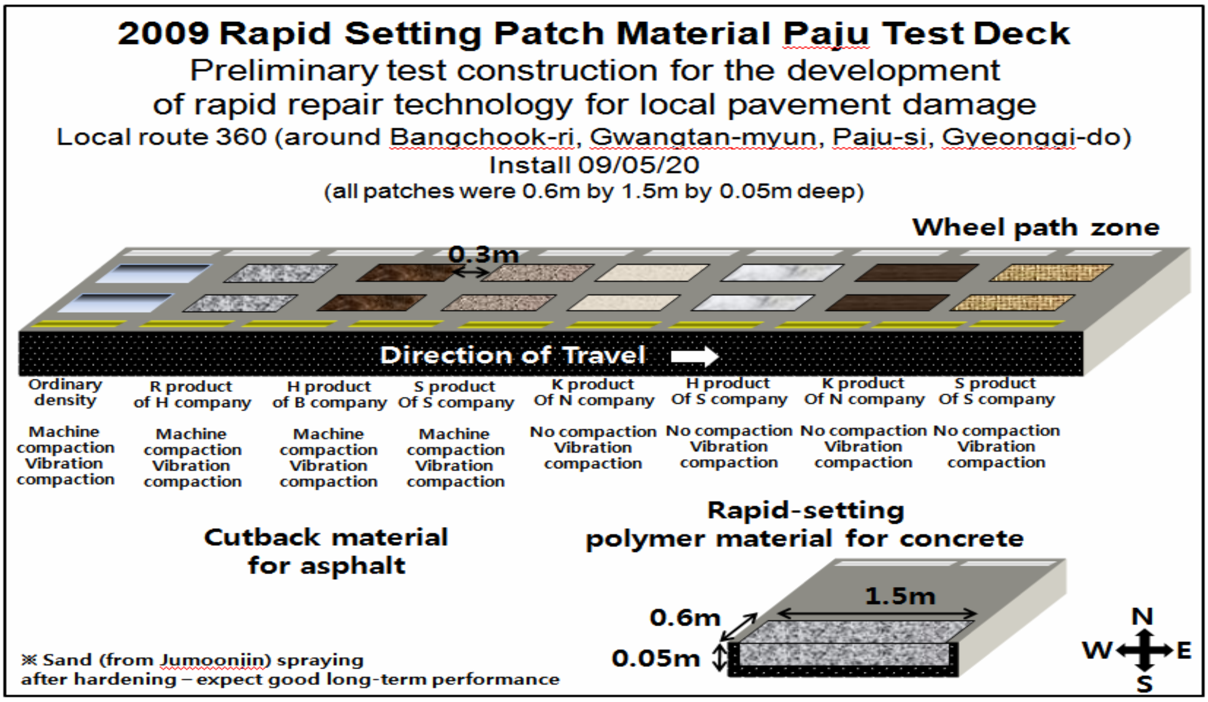


Figure 10. Plan for field test construction

Figure 11. Field test construction images Conclusion

3. Conclusion

This study aimed at examining the characteristics of rapid repair material for damaged pavement of SMART Highway and preparing the alternatives, and the following conclusions of this research task are summarized and described as follows.

The admixtures for asphalt were of pre-mixed type of cutback asphalt and were prepared at normal temperature in order to deal with the problems in production, storage and workability. The comparison test result indicated that they were useful only as temporary measures for emergency repair of local damage rather than their use as good long-term or short-term performance materials.

The admixtures for concrete were rapid-setting polymer mortar, and the difference in the initial and final setting time was analyzed by the mix type. It was found that they were influenced by the hardening speed due to their characteristics as rapid repair materials and that there were needs for the alternative to obtain adequate void (air) content within the concrete in order to obtain appropriate water-cement (W/C) ratio, workability, and durability.

Finally, it is deemed from field test construction of this study that the strength and bond strength are very important factors for the application of emergency repair materials for pavement damage of SMART Highway and that the economic feasibility of such repair construction must be attained by identifying the strict standards and analyzing the characteristics of such materials in order to deal with these factors of influence in the future.

Acknowledgement

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